Good welding practice Stainless Steels

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Materials Joining and Engineering Technologies

Stainless Steels

- Five basic types of stainless steels,
  - Austenitic, most common
  - Ferritic
  - Martensitic
  - Duplex, main use oil & gas
  - Precipitation Hardened

- All have different properties and hence different applications:

- Most are weldable, but with different problems.
  - Special case - Precipitation Hardened

Typical Stainless applications

- **Austenitic –**
  - Good corrosion resistance, low temperature ductility, high temperature oxidation resistance
  - process plants, cryogenics, corrosive applications, used over wide temperature range
- **Ferritic –**
  - Lower cost variant, good strength but lower corrosion resistance
  - bulk handling equipment, road / rail vehicles, not for elevated temperatures (<300°C)
- **Martensitic-**
  - High strength / high hardness,
  - aerospace, medical, petrochemical
- **Duplex-**
  - Good strength and corrosion resistance
  - oil & gas extraction / production, not for elevated temperatures (<300°C)

Arc Welding Processes

- **ARC WELDING**
  - MANUAL METAL ARC — MMA (SMAW)
  - TUNGSTEN INERT GAS SHIELDED — TIG (GTAW)
  - METAL ACTIVE GAS SHIELDED — MAG (GMAW)
  - FLUX CORED ARC WELDING — FCAW
  - SUBMERGED ARC WELDING — SAW
  - PLASMA ARC WELDING — PAW
  - ELECTRON BEAM WELDING — EBW
  - LASER BEAM WELDING — LBW

- **SOLID PHASE WELDING**
  - FRICTION WELDING — FW
  - FRICTION STIR WELDING — FSW

Austenitic stainless steels
Welding Problems

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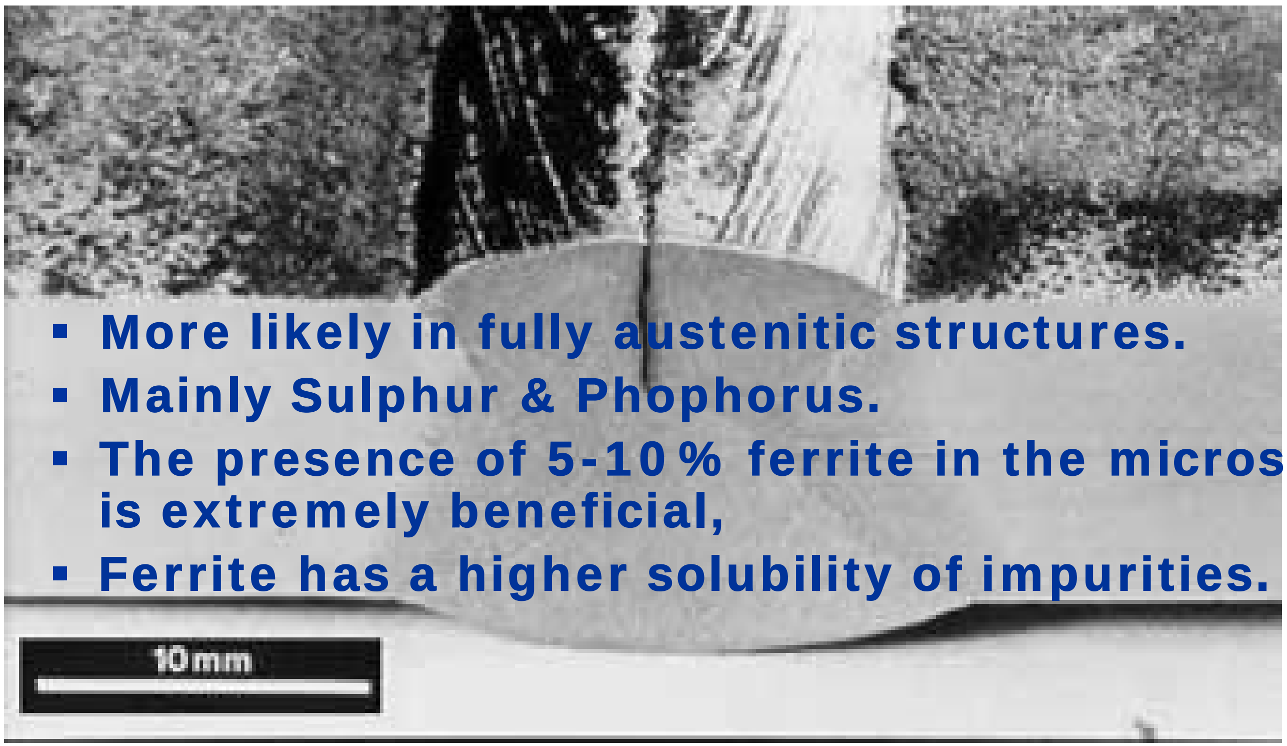
Austenitic stainless steels

- **Welding problems**
  - **Weld metal solidification cracking**



- **More likely in fully austenitic structures.**
- **Mainly Sulphur & Phophorus.**
- **The presence of 5-10% ferrite in the microstructure is extremely beneficial,**
- **Ferrite has a higher solubility of impurities.**

Austenitic stainless steels

- **Solidification cracking prevention.**
  - **Welding Consumables**
    - **The choice of filler material composition is crucial.**
    - **Filler choice depends on required mechanical and corrosion properties – often higher alloy (nominally matching)**
    - **Autogenous welds are possible, but usually welded with matching filler or slightly overalloyed.**
    - **e.g. when welding Type 304 stainless steel, a Type 308 filler material which has a slightly different alloy content, is used.**
    - **Weld metal composition can be predicted from the Schaeffler diagram**

Austenitic stainless steels

Schaeffler diagram

Stainless steel composition determines whether solidification is initially ferrite (δ), austenite (γ), or a mixture of both (δ+ γ)

Austenite stabilisers, Ni_{eq}

- **Carbon, Nickel, Nitrogen, Manganese, Copper**

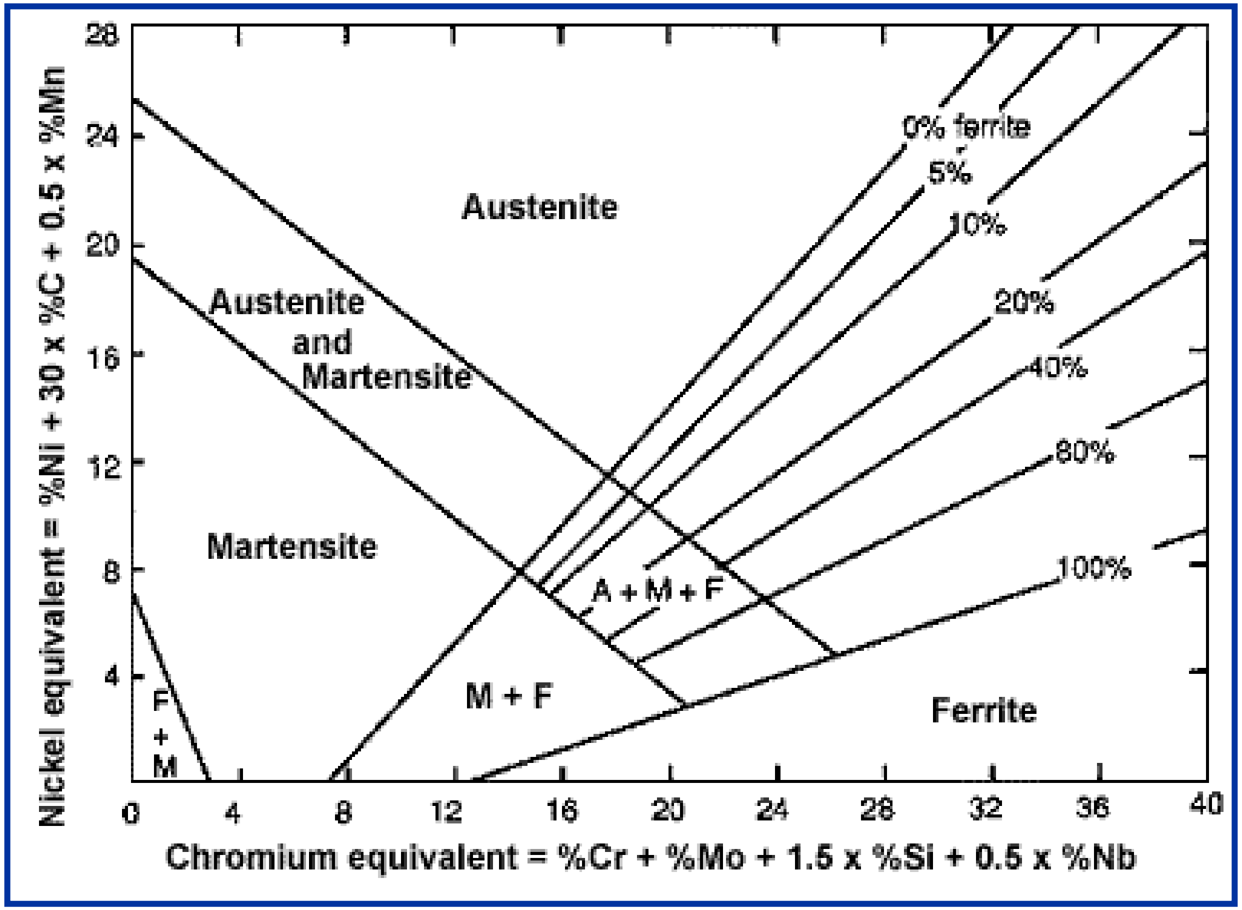
Ferrite stabilisers, Cr_{eq}

- **Chromium, Molybdenum, Tungsten, Niobium, Silicon**

Ferrite measured by magnetic instrument or by metallography

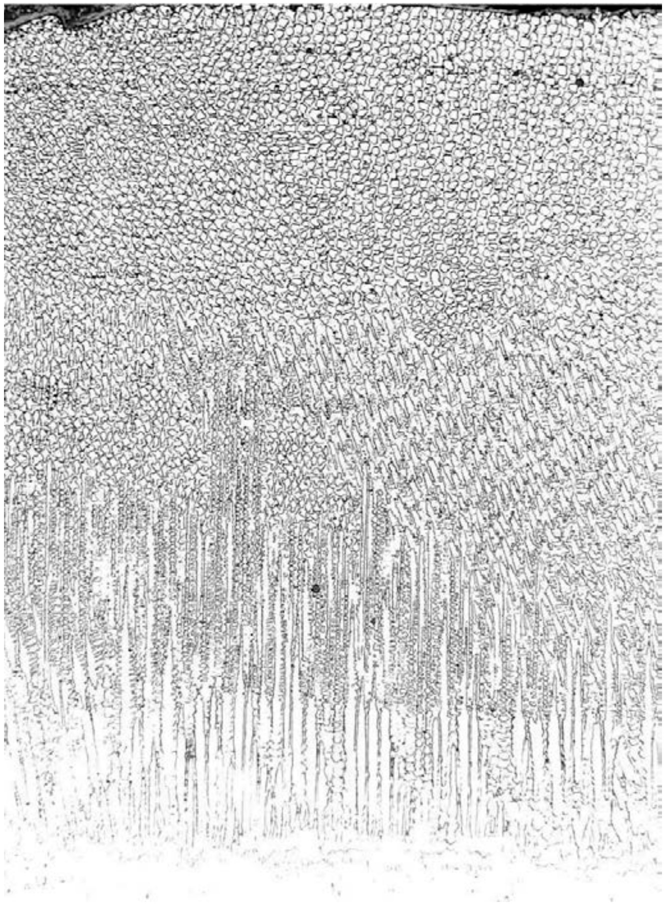
Austenitic stainless steels

- **Schaeffler diagram predicts weld metal phases**

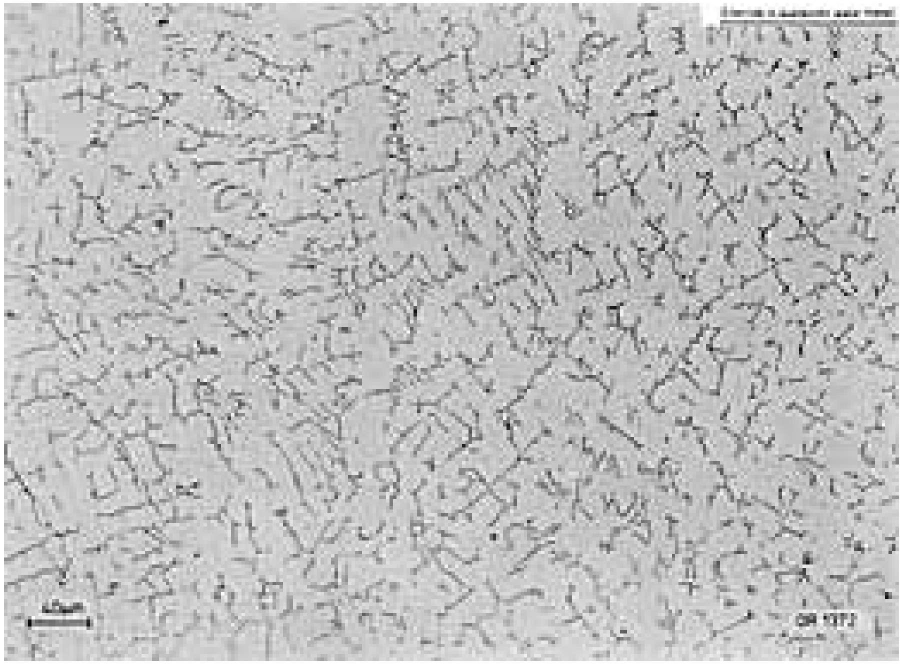


Weld microstructure

- **Weld bead**

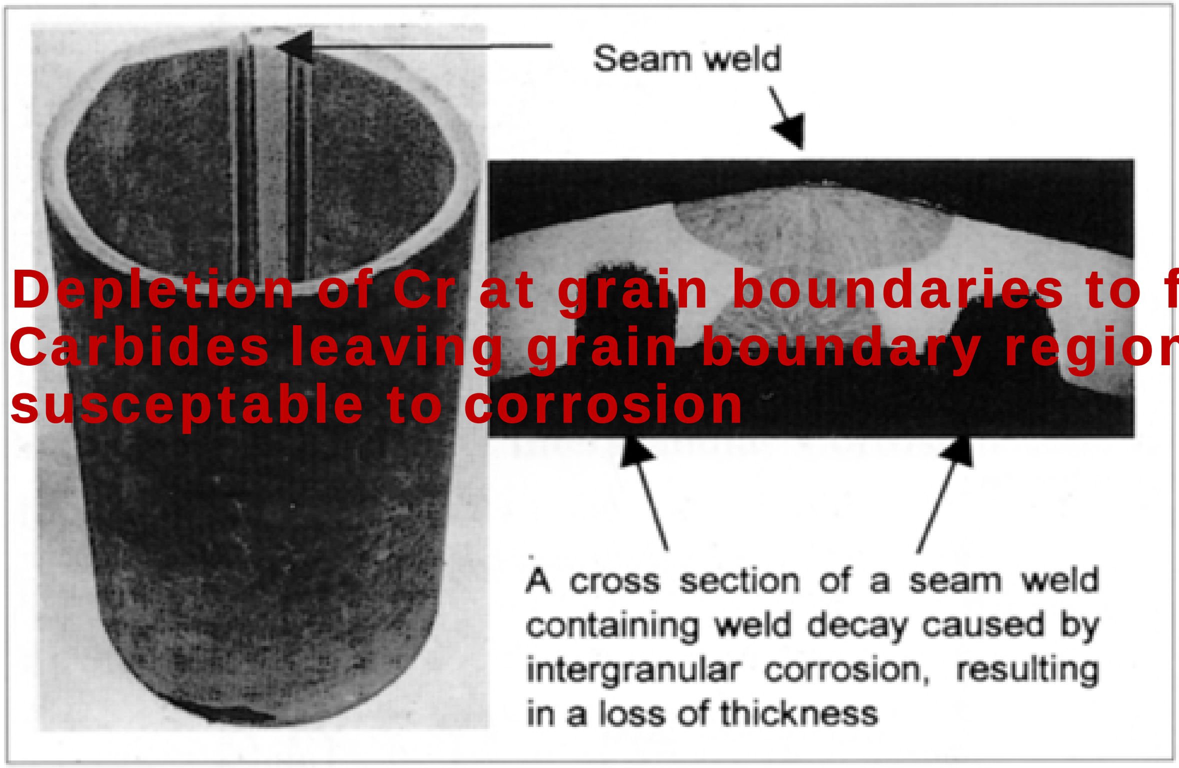


- **Delta ferrite (dark regions)**



Austenitic stainless steels

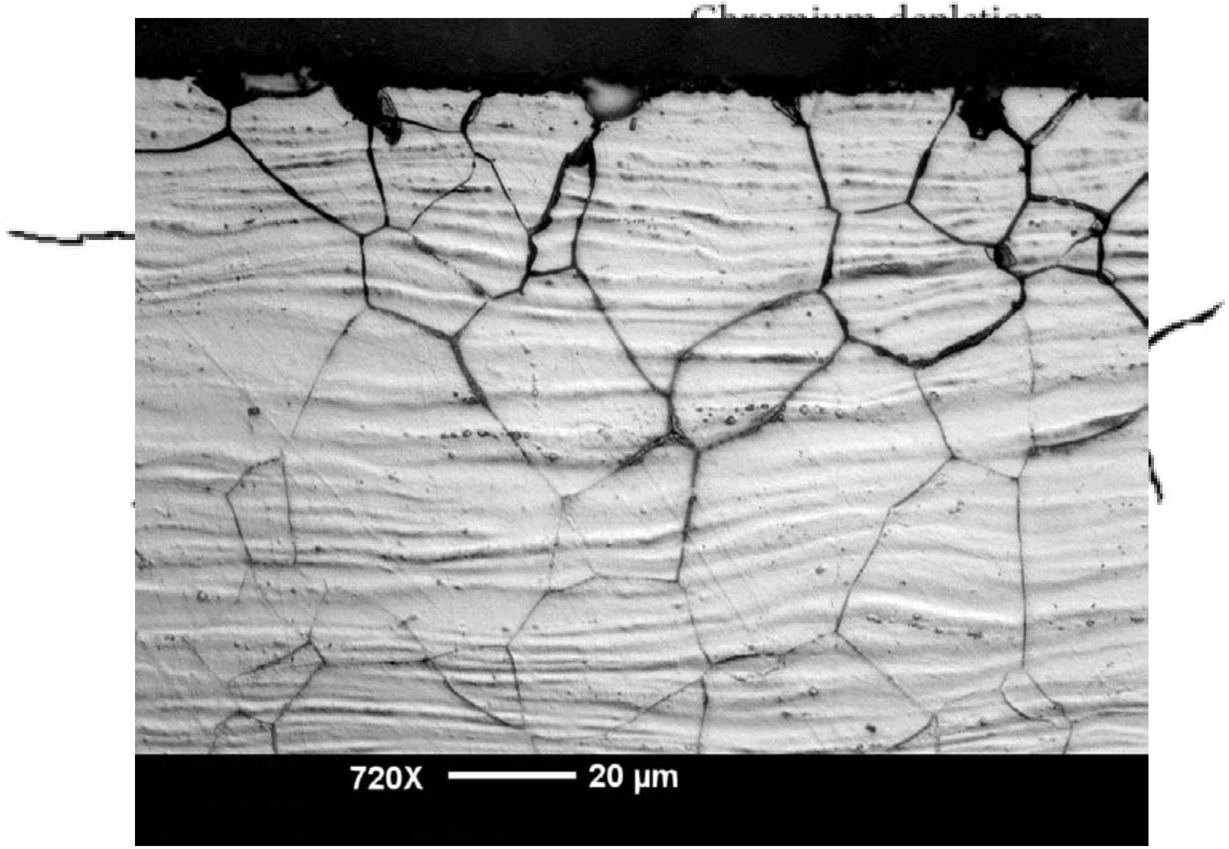
- **Welding problems**
  - **Weld Decay (sensitisation)**



  - **Depletion of Cr at grain boundaries to form Cr Carbides leaving grain boundary regions susceptable to corrosion**

Austenitic stainless steels

- **Weld Decay (sensitisation)**



Austenitic stainless steels

- Weld Decay (sensitisation) prevention.
  - Materials
    - Use stabilised materials, grades 321 (Ti) or 347 (Nb).
      - Ti or Nb carbides form in preference to Cr leaving Cr in grains for protection.
    - Use L grades with <0.03% Carbon,
      - insufficient C to form carbides

Austenitic stainless steels

- **Welding issues;**
- **Distortion**
  - **Low Thermal conductivity**
    - **16 W / m°C compared to 47 W / m°C for Csteel**
  - **High Coefficient of Expansion**
    - **20 µm / m°C compared to 13 µm / m°C for Csteel**
- **Minimise**
  - **Weld volume**
  - **Accurate fit up:**
    - **avoid wide gaps and misaligned edges**
  - **Maintain low interpass temperature (~150°C max).**
  - **Avoid high heat input techniques**
    - **i.e. large weave, high welding current, slow travel speed**

Austenitic stainless steels

- **Other issues:**
  - Weld cold: no problem with phase transformations and avoids precipitation
    - No preheat required, as cold cracking not an issue.
      - Austenite solubility of H_2 is 8x that of Ferrite
      - Rutile electrodes are acceptable and easier to use.
  - Avoid Post-weld heat treatment,
    - not normally required
    - risk of precipitation and sensitisation, 500 - 800°C
  - Avoid non-removable backing rings
    - risk of crevice corrosion

Ferritic stainless steels
Welding Problems

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Ferritic stainless steels

- **Sensitive to grain growth**
  - loss of toughness, embrittlement
  - limited to 250°C service temperature
  - can lead to cracking in weld or HAZ of highly restrained joints and thick section material.
- **Hydrogen cracking**
  - Can suffer cold cracking similar to Carbon Steels.
- **Filler metals:**
  - matching, austenitic or nickel alloy

Ferritic stainless steels

- Usually parent materials are thin plates or tubes.

- Austenitic Fillers
  - When welding thin section material, (< 6mm) use an austenitic filler and no special precautions are necessary.
  - In thicker material, if using an austenitic filler to produce a tougher weld metal, it is necessary to employ a low heat input and max interpass of 150 °C to minimise the width of the grain coarsened zone.
- Nickel Fillers
  - Used if PWHT required

Ferritic stainless steels

- Matching Fillers
  - If welded with matching filler, preheat and PWHT (due to hard martensitic formation).
  - Preheat temperature should be within the range 50-250 °C depending on material composition.
  - Preheating will reduce the HAZ cooling rate, avoiding formation of martensite and reduce residual stresses.

Martensitic stainless steels
Welding Problems

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Martensitic stainless steels

- **Welding Problems**
  - **Hydrogen cracking**
    - **Normally matching consumables.**
    - **High hardness in the HAZ makes this type of stainless steel very prone to hydrogen cracking above >3mm. The risk of cracking increasing with the carbon content.**
    - **Take precautions to minimise hydrogen**

Martensitic stainless steels

- Precautions which must be taken to minimise the risk, include:
  - using low hydrogen processes
  - preheating to around 200 to 300 deg.C.
  - maintaining the recommended minimum interpass temperature.
  - Allow cooling to ambient to ensure complete transformation to martensite prior to PWHT
  - carrying out post-weld heat treatment, e.g. at 650-750 deg.C.

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Duplex stainless steels

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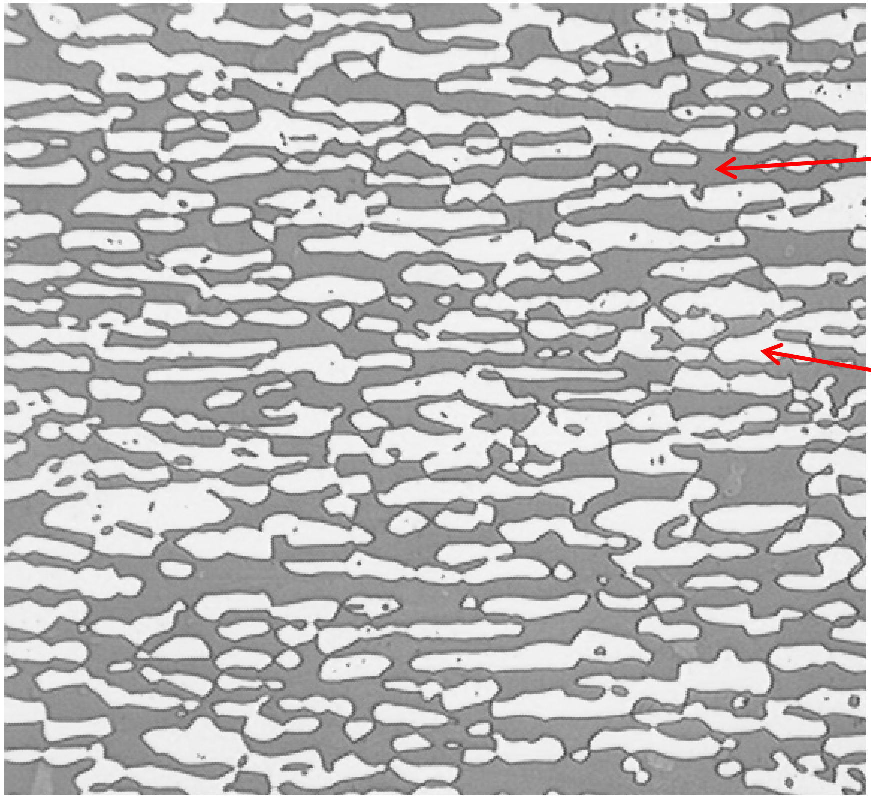
Duplex stainless steels

- **Complex !**



Ferrite matrix - dark
High strength
Resistance to SCC

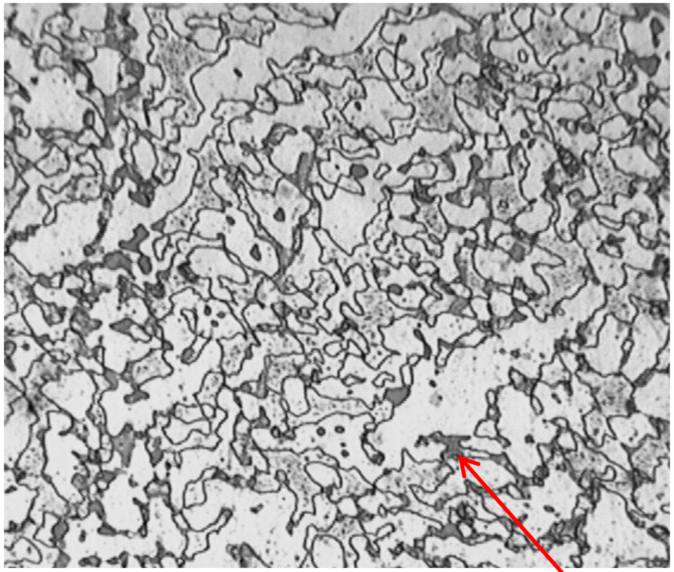
Austenite - light
Corrosion resistance
Toughness

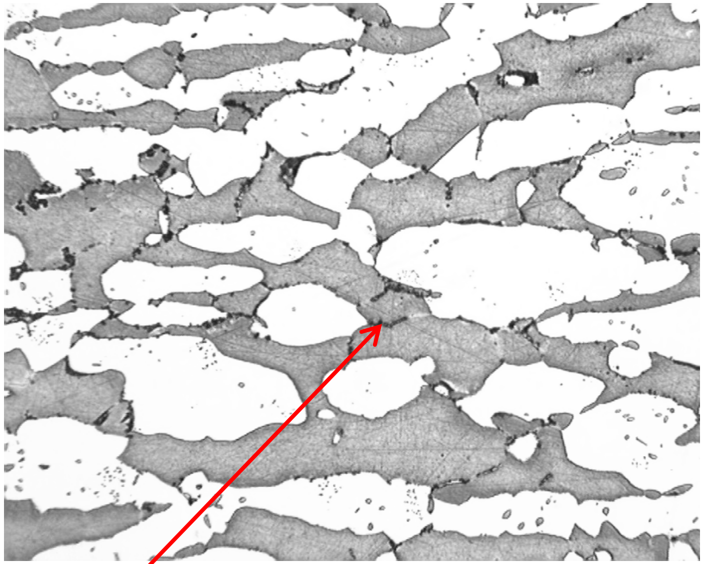
Duplex stainless steels

- **Complex !**
- **Preheat is not normally required.**
- **Heat input and the maximum interpass temperature must be controlled.**
  - **Too high cooling rate produces high % Ferrite**
  - **Too slow cooling rate precipitates third phases**
- **Choice of filler**
  - **critical to produce a weld metal structure with a ferrite-austenite balance to match the parent metal requirements in as welded condition.**
  - **To compensate for nitrogen loss, the filler may be overalloyed with nitrogen or the shielding gas itself may contain a small amount of nitrogen.**

Duplex stainless steels

- **Complex ! Get it wrong.**





Third phase precipitates

Low toughness

Low corrosion resistance

Welding Stainless steels to Carbon/Low alloy steels

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Stainless to Carbon/Low alloy steels

- **Consumables**
  - Use Austenitic consumables or consumables matching stainless grade, alternatively use Ni based consumables.

Stainless to Carbon / Low alloy steels

- **Austenitic Stainless**
  - **Welding Problems**
    - Dilution of weld metal from the Low alloy base material .
    - possible formation of hard brittle structures,
    - use an overalloyed austenitic stainless filler material, type 309 (24% Cr 12% Ni), weld deposit will be ductile & can tolerate high dilution from carbon /low alloy steel
    - pre-heat is not usually required
    - Upto 15% ferrite to avoid hot cracking
    - Not suitable for PWHT or above 400°C due sigma phase formation.

Stainless to Carbon/Low alloy steels

- **Austenitic Stainless**
  - **Welding Problems**

    Alternative Ni-based consumables (ENiCrFe-2 and ENiCrFe-3, Alloy 600 type) for PWHT.
  - **PWHT still a problem for the Austenitic Stainless**
  - **Recommended fabrication sequence for PWHT.**
    1. **Butter the ferritic steel with Ni-base consumables**
    2. **Apply the PWHT to ferritic steel+buttering**
    3. **Complete the joint with Ni-based consumables**

Cross contamination presentation

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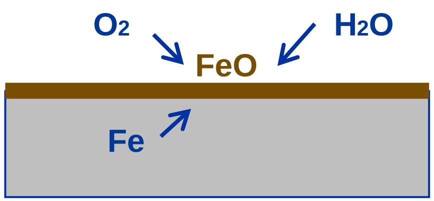
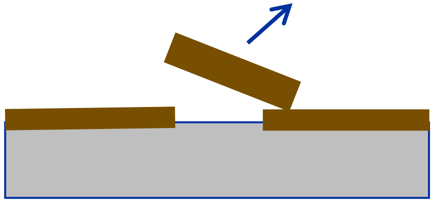
Basic Corrosion

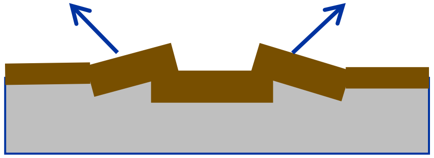
- Carbon/Low alloy steels
- $Fe + O_2 = Fe_xO_Y$ (Rust)
  - Requires an electrolyte for the reaction to occur, normally water, moisture in the atmosphere can be sufficient.





But FeO is reactive & 4x volume of Fe. Stresses created in formation cause FeO to flake off. Exposing more Fe.

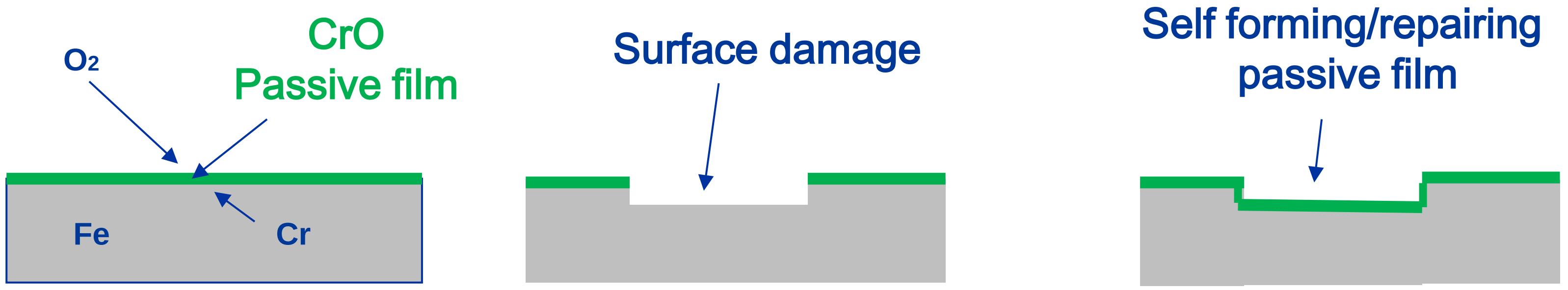
Which in turn corrodes forming more FeO



And the process continues, reducing steel thickness.

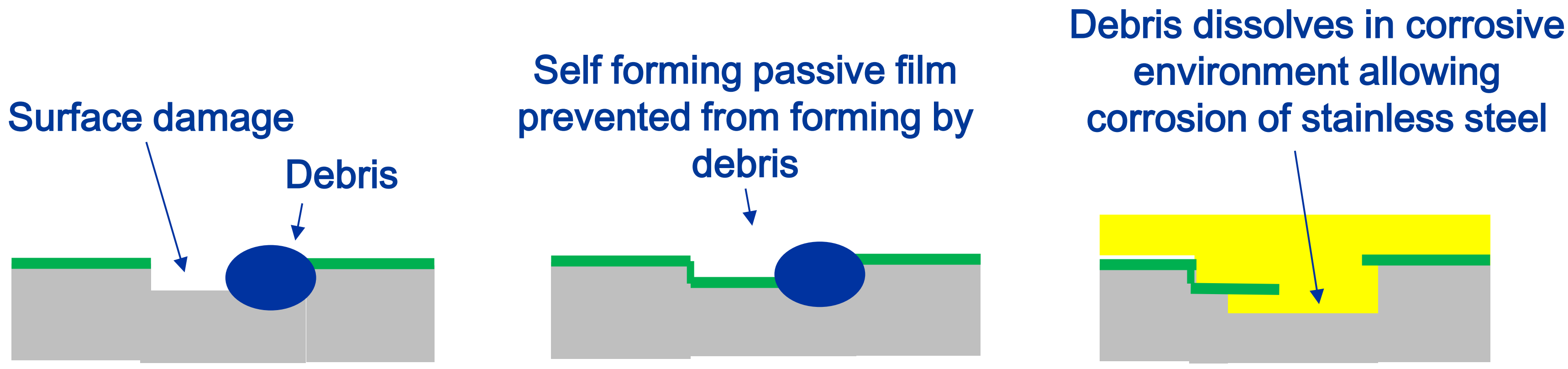
Basic Corrosion

- **Stainless steels contain more than 11% Chromium.**
  - Cr is more reactive with O_2 than Fe and consequently a Cr oxide is formed in preference to Fe_xO_Y and forms without an electrolyte.
  - Cr_xO_Y is a coherent passive layer (protective film), which is approx. 10 micron thick.
  - Normally self repairing in air, within seconds.
  - The CrO layer prevents further corrosion of the steel.



Basic Corrosion

- If Stainless steel is damaged with non corrosion resistant material, i.e. Carbon Steel
  - Passive layer is prevented from reforming
  - This can then lead to corrosion of stainless steel in a corrosive environment.



Cross contamination

- **Prevent carry over of particulate contamination**
  - **avoid contact with carbon steels**
    - **chains, forks, benches and hammers**
  - **consider forming processes**
    - **Rolls, pressbrakes and guillotines**
  - **use dedicated tools for stainless steel**
    - **INOX grinding discs, SS wire brushes**
  - **avoid walking on stainless steel material**
    - **Grinding Dust on soles of boots**

Cross contamination

- **Fabrication.**
  - **Clean joint and adjacent parent material to remove dirt, grease, oil, paint.**
    - **Heat from welding can cause elements in these to attack CrO layer or diffuse into microstructure, grain boundaries.**
  - **Temporary attachments**
    - **materials should be compatible with the parent material**
    - **preventing dilution and contamination**

Cross contamination

Fabrication

Arc strikes

damage the CrO layer , creating oxidation
act as initiation points for pitting corrosion and cracks

Other considerations

use chloride free marker pens, tapes etc.
Inks & glues may contain halides which will attack the CrO layer.

Cross contamination

- **Detection.**
  - Detection of free iron contamination on the surface by Ferroxyl test, only applicable to austenitic's. Contains Potassium ferricyanide
- **Post cleaning.**
  - Appropriate post-weld cleaning to obtain good corrosion resistance , remove spatter, slag, arc strikes, oxides (discolouration) around weld.
- **Pickle and passivate**
  - if required to restore protection.
  - Note. Only restores surface not contamination within the weld metal.

Cross contamination

Stainless steels corrode!

- Welds are more prone to corrode than parent material of same composition.
- Intergranular corrosion (weld decay)
- Crevice corrosion
- Pitting corrosion
- Stress Corrosion cracking
  - Chloride Stress Corrosion cracking
  - Sulphide Stress Corrosion cracking

- Cleanliness is important to avoid initiating corrosion

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Stainless Steel - Quality Fabrication Seminar

End of presentation

Any Questions

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